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Recovery of Muscle Strength and Power After Limb-Lengthening Surgery

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ABSTRACT. Barker KL, Lamb SE, Simpson HRW. Recovery of muscle strength and power after limb-lengthening surgery. *Arch Phys Med Rehabil* 2010;91:384-8.

Objective: To report muscle strength, power, and function after limb-lengthening surgery performed by using the Ilizarov technique.

Design: Prospective, longitudinal observational study of a cohort of consecutive patients who underwent limb-lengthening distraction followed up for 2 years after surgery.

Setting: National Health Service hospital specializing in orthopedic surgery.

Participants: Patients (N=16) who had undergone limb-lengthening surgery performed by using the Ilizarov method (11 men, 5 women; mean age=27y; range, 13-56y).

Interventions: None.

Main Outcome Measures: Muscle strength and power were assessed by using 2 validated measures: isokinetic concentric strength of the quadriceps and hamstrings measured by using a dynamometer and leg extensor power. Measures were recorded preoperatively and at 6, 12, and 24 months after the completion of lengthening. Function was measured by 2 timed tests of functional performance: stair climbing and sit-to-stand.

Results: Overall results were good with high reports of function and satisfactory clinical examination. Both concentric muscle strength and leg power showed a clear pattern of decreased muscle strength at 6 months after frame removal, improving throughout the study period until it was within 3% of the preoperative value at 2 years. By 2 years, self-reported function and ability to complete timed functional tests had returned to or improved on the preoperative values. Muscle strength remained slightly below the preoperative value; this was more pronounced in the quadriceps than the hamstrings. There was no association between muscle strength and the amount of lengthening that had been undertaken.

Conclusions: This study suggests that there is a small residual decrease in muscle strength and power after limb-lengthening surgery but that these do not adversely impact on a patients' ability to perform everyday functional activities.

Key Words: Ilizarov technique; Muscle strength; Rehabilitation.

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LIMB LENGTHENING USING distraction osteogenesis allows correction of limb-length inequality and deformity that may arise because of nonunion or malunion of fractures or because of congenital deformities. It successfully addresses issues of limb length but is a process associated with a high complication rate and causes significant changes to the morphology of both muscle and nerve tissue. It is documented that decreases in muscle strength occur during and after limb-lengthening surgery.¹⁻⁴ Young et al³ stated that muscle weakness may not resolve for 2 years after lengthening and occurs because of intrinsic axonal neuropathy secondary to the lengthening process rather than from simple disuse. Electromyographic changes occur in the muscle after limb lengthening, and these are seen for a prolonged period of time before reverting to normal despite normal histopathology.² Kaljumäe et al⁵ concluded that the amount of damage to neuromuscular tissue correlated with the extent of the lengthening of the bone. They reported that limb-lengthening surgery has a permanent effect on the neuromuscular tissues, slowing motor-unit recruitment, and increasing fatigability, a finding that is in agreement with earlier reports.^{6,7}

Conversely, Holm et al⁸ performed isokinetic testing of muscle strength of the quadriceps and hamstrings in 9 patients undergoing bilateral femoral lengthening for short stature. In all of the patients except one, there were only small changes in muscle strength. Currently, little is known about the long-term functional recovery of strength or function. The aims of this study were to document the effects on muscle strength, power and subsequent lower limb function, of distraction osteogenesis performed by using the Ilizarov technique.

METHODS

Participants

Sixteen consecutive patients undergoing limb-lengthening surgery performed by using the Ilizarov method of distraction osteogenesis were studied prospectively over a minimum period of 2 years. All patients undergoing limb lengthening during the study period were invited to participate in the study; ethical committee approval had been obtained. The etiology of the limb-length discrepancy is described in table 1. There were 11 men and 5 women, with a mean age of 27 years 4 months (13-56, SD=10.18). Leg lengthening was performed by using the Ilizarov circular fixator in 11 cases and a combination of the Ilizarov fixator^a with an Orthofix unilateral fixator^b in 5 cases. All surgery was performed by a single surgeon (HS). The technique used has been described previously by the authors.⁹

All of the patients received regular physical therapy based on reported programs; these predominantly focused on regaining range of motion at the knee and hip and strengthening exercises for the quadriceps and hamstrings.¹⁰⁻¹² The physical outcome

List of Abbreviations

LEP	leg extensor power
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Table 1: Description of Study Participants

Case	Etiology	Sex	Age (y)	Site	Length (mm)	% Lengthening
1	Malunion	M	34	Femur	31	7.9
2	Malunion	F	28	Femur	25	6.0
3	Nonunion	M	30	Femur	50	10.6
4	Nonunion	M	30	Femur	52	12.3
5	Malunion	M	27	Femur	66	12.2
6	Malunion	M	27	Femur	44	16.1
7	Nonunion	M	22	Femur and tibia	73	15.4
8	Cerebral palsy	F	18	Femur	35	9.4
9	Hip dysplasia	M	24	Femur	32	6.5
10	Malunion	M	56	Femur and tibia	58	13.1
11	Nonunion	M	37	Femur	31	5.2
12	Nonunion	F	22	Femur	34	8.1
13	Nonunion	M	27	Femur and tibia	85	18.0
14	Nonunion	M	32	Femur	29	7.6
15	Avascular necrosis	F	13	Femur and tibia	56	7.8
16	Hemihypertrophy	F	13	Femur and tibia	71	10.2

Abbreviations: F, female; M, male.

assessments were administered to the patients on the day before surgery and at 6, 12, and 24 months after surgery. The same person (KLB) performed all the measurements.

Stair Climbing

Subjects climbed a staircase with 13 steps, each of a 19-cm depth. The number of stairs that they ascended and descended in 60 seconds was recorded.

Sit-to-Stand

Subjects were seated in a chair with the seat 49cm from the ground (British standard height) and with their feet placed flat on the floor in front of them. Patients were asked to fold their arms, and with their arms folded, on the command “go” they were asked to stand upright to a position with their knees straight and then sit back down immediately. The number of times that each subject rose and returned to the starting position in 60 seconds was recorded.

Muscle Strength: Isokinetic Dynamometry

Concentric muscle strength was measured by using isokinetic dynamometry, allowing strength to be measured through their range of normal functional use.¹³ All patients were tested on the Kin-Com 125 isokinetic dynamometer^c following a set protocol that measured peak isokinetic torque of the knee quadriceps and hamstrings during concentric muscle activity. Measurements were taken preoperatively and at 6, 12, and 24 months postoperatively at an angular velocity of 60°/s. This velocity was chosen because it has been used in previous work reporting test-retest reliability of the KinCom isokinetic dynamometer,¹⁴ allowing us to replicate a published protocol with high reported reliability. The range of motion for the knee was set between 0° and 90° flexion. Patients were positioned in the seat so that the axis of the knee joint was aligned with the axis of rotation of the machine. They were stabilized within the seat using straps to secure the pelvis, thigh, and ankle with their arms held in a relaxed position. Both legs were tested; the nonoperated leg was tested first to allow comparisons to be made between the index and control limbs. The patient warmed up on a cycle ergometer and was familiarized with the equipment before data capture. Patients then completed 5 submaximal and 1 maximal contraction as both a warmup and to become familiar with the movement required. They rested for

1 minute before the testing began. Three concentric maximum knee extensions were performed at 60°/s. Each contraction was followed by a 30-second rest. The protocol was then repeated for knee flexions. Standardized verbal commands were given with strong encouragement to produce a maximum effort. For each of the 3 repetitions, we calculated the mean and peak values. The mean peak torque data were used for the subsequent analysis.

Muscle Power: Leg Extensor Power

A further measure of lower-limb performance was recorded (LEP). It is suggested that measures of maximal LEP are of more relevance to function than maximal quadriceps strength measures because the motion replicates movement patterns that are a common component of such tasks as walking and climbing stairs.^{15,16}

Body weight was recorded by using a set of calibrated bathroom scales. Patients were measured by using the Leg Extensor Power Rig.^d It consists of a seat and a footplate connected through a lever and chain to a flywheel. The subjects were seated in an upright position settled against the back of the seat. The seat position was determined by comfortable extension of the knee in conjunction with full depression of the foot pedal varying with subjects' leg length. Patients were asked to make 2 to 3 submaximal practice pushes and then 5 maximal efforts. Strong verbal encouragement was given after the instruction to “push the footplate down as hard and as fast as possible.” There was a rest period of 20 seconds between efforts. After each attempt, the power produced was displayed in watts as a numeric display and recorded. The output was a product of the combined force of the leg extensor muscles, and the pedal velocity was generated during a single-leg extension. The hip, knee, and ankle extensor muscles all contributed to the extension force. The highest-recorded power output was used. Both legs were measured. Measures of LEP were summarized as relative power (ie, absolute power divided by body weight) because this index has greater functional relevance and to allow comparison with other studies.¹⁶

Data Analysis

Data were analyzed by using the statistical package SPSS version 14.^e There were no missing data. Data were tested for normality by using a Kolmogorov-Smirnov test. The data were normally distributed.

A repeated-measures analysis of variance (using post hoc Bonferroni testing) was used to establish the significance of changes over time. This sought to establish the difference in scores at the differing time points. Differences between the index and control limb at each time point were analyzed by using a paired *t* test. The alpha level for the analysis was set at $P < .05$. Associations between different variables with etiology and the amount of limb lengthening were explored by using Pearson product-moment correlations.

RESULTS

Isokinetic Dynamometry-Concentric Muscle Strength

There was a significant difference between the operated and unoperated limbs in the mean isokinetic torque for both the quadriceps and hamstrings at all times. Preoperatively, the difference between the limbs was significant at the $P < .01$ level. Thereafter, the differences between the limbs were greater, with the differences being significant at the $P < .005$ level for both the quadriceps and hamstrings at 6 months and 1 year and for the quadriceps at 2 years. The difference for hamstrings at 2 years was less ($P = .064$). The muscles on the operated side were weaker throughout (table 2).

Figure 1 shows the changes in index/control limb torque over time. A significant decrease in the index/control torque ratio for the quadriceps was found between preoperative and 6 months after frame removal ($P = .01$). This improved at 1 and 2 years but remained decreased compared with the preoperative value. The decrease in index/control torque for hamstrings between preoperative and 6 months was less marked and did not reach statistical significance ($P = .121$). The index/control torque ratio for hamstrings was found to significantly increase from 1 to 2 years after frame removal ($P = .008$). The changes in the quadriceps and hamstring torque over time showed that the changes in ratio are the effect of changes in the operated limb rather than the control limb (fig 2).

There was no correlation between either the amount of lengthening and strength of either the quadriceps ($r = .203$) or hamstrings ($r = .091$). There was no association between the percentage of lengthening and strength of either the quadriceps ($r = .097$) or hamstrings ($r = .141$) nor was there any association with the etiology of the limb-length discrepancy and strength ($r = .232$ quadriceps and $r = .478$ hamstrings).

Leg Extensor Power

The recovery of LEP over time is shown in figure 3. There was a significant decrease in LEP between the preoperative and 6-month measurements ($P < .001$). Thereafter, power improved with statistically significant improvements between 6 months and 1 year and between 1 and 2 years ($P < .001$). At 2 years,

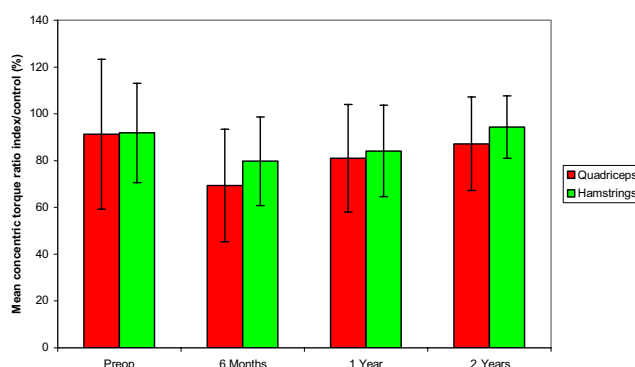


Fig 1. Changes over time in the operated (index) and control limb isokinetic torque ratio for quadriceps and hamstrings.

there was no significant difference from the preoperative measurement.

There was no correlation between the amount of lengthening and LEP ($r = .197$, $P < .465$) or with etiology ($r = .008$, $P < .976$). There was no correlation between LEP and the etiology of the leg-length discrepancy ($r = .471$).

The strength of association for the measurements of concentric quadriceps strength and extensor power, stair climbing, and sit-to-stand were explored and found to correlate well, both preoperatively and at 2 years. There were significant positive correlations between the preoperative measurement of LEP and the ability to climb stairs and perform sit-to-stand. There were also significant correlations between the measurement of concentric quadriceps torque and these activities (stair climbing [$r = .737$, $P = .01$] and sit-to-stand [$r = .770$, $P = .01$]). There was no association between muscle strength or power and the speed of walking (table 3).

DISCUSSION

A relative deficit in the strength of the quadriceps and hamstrings was observed in the index limb preoperatively. This is attributed to a decreased use of the shorter, or injured, limb before surgery and by the patients compensating and favoring their unaffected limb.

The changes in muscle strength over time were interesting. Quadriceps strength decreased more than hamstrings strength at 6 months, and at 1 year the quadriceps torque ratio was still decreased. At the final measure, 2 years after frame removal, the quadriceps strength had not returned to the preoperative value. However, the effect on the hamstrings strength was less pronounced. After an initial decrease at 6 months, the strength increased steadily until at the final measurement it had slightly exceeded the preoperative value. It is not clear why the quadriceps should tolerate lengthening less well than the hamstrings.

Kaljumae et al⁵ showed by electromyographic studies that 6 to 15 years after lengthening there was a permanent effect on neuromuscular tissue, with suppressed motor-unit recruitment and increased fatigability of the vastus medialis. They postulated that this was caused by the greater relative distribution of type I fibers in this muscle. Maffulli and Fixsen⁴ also reported that there remained a weakness in the lengthened limb 2 years after surgery. Their group of subjects were all affected by congenital femoral hypoplasia, but the differences in strength remained even when corrections for muscle and bone cross-sectional area were made. Conversely, Holm et al⁸ reported unchanged muscle function on isokinetic testing between 2 and

Table 2: Paired *t* Test of Differences Between Operated and Unoperated Limbs

	Mean (Nm) \pm SD	<i>t</i> test	Significance
Quadriceps preoperatively	18.10 \pm 36.0	-2.01	.063
Hamstrings preoperatively	13.75 \pm 29.3	-1.87	.080
Quadriceps 6 months	43.56 \pm 30.0	-5.80	.000
Hamstrings 6 months	24.31 \pm 21.5	-4.50	.000
Quadriceps 1 year	28.93 \pm 26.0	-4.40	.000
Hamstrings 1 year	18.43 \pm 20.3	-3.60	.003
Quadriceps 2 years	20.25 \pm 24.7	-3.27	.005
Hamstrings 2 years	6.68 \pm 13.3	-2.00	.064

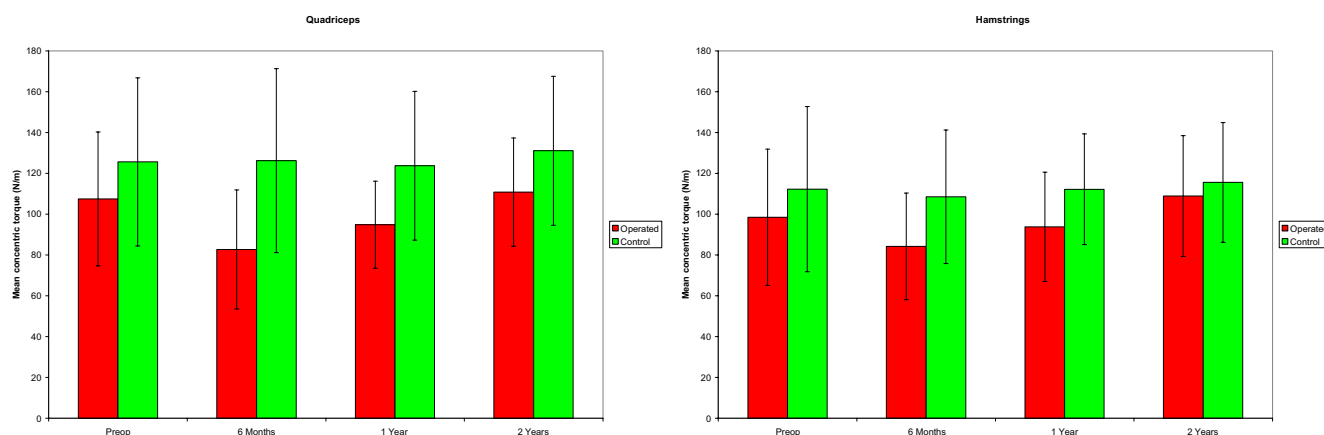


Fig 2. Changes over time in isokinetic muscle torque comparing index and control limbs.

3 years after surgery affecting the extensor mechanism of the knee. However, it is of note that all of Holm's patients were operated on for short stature, a group who is known to have soft tissues that tolerate stretch better than normal subjects. The cause of the limb-length discrepancy in the subjects in the study reported here and those reported by Kaljumäe et al⁵ were both congenital and acquired.

The effect of surgery on LEP was very similar to that of concentric quadriceps strength. At 2 years after frame removal, LEP had almost returned to the preoperative value with just a 2.7% decrease from the preoperative value for LEP. For the concentric quadriceps score, the difference between the preoperative and 2-year values was 3%. Thus, it can be seen that the measures of muscle strength and power correlate well.

The testing procedure for the LEP is much simpler, taking an average of 20 minutes per patient compared with 45 to 60 minutes for testing by the isokinetic dynamometer. Simpson and Kenwright¹⁷ cited an incidence of fracture in the early period after frame removal of 9.4%. It was this risk that precluded testing in this cohort of patients at a time period earlier than 6 months after frame removal. However, the LEP rig mimics the forces that are used in everyday activities, and the generation of force is along the long axis of the bone, minimizing the risk to the regenerate bone. It is also advantageous because it is a closed kinetic chain exercise, which many

authors believe to be safer and more functional.^{18,19} Thus, it may be a safer method of testing muscle function than isokinetic dynamometry, which produces torque and is performed as an open kinetic chain exercise.

The protocol selected for the isokinetic dynamometry testing may have influenced the results. We chose to test at a slow angular velocity because previous reports had shown good reliability with this protocol. However, this may be criticized because slower angular velocity testing is considered by some to be less relevant than faster angular velocity testing at 300°/s or higher that more closely replicates those found in everyday functional activities.²⁰

Likewise, we chose to always test the nonoperated leg first as per the guidelines of Wilk.²⁰ This may have introduced bias into the results caused by a learning effect. We decided not to randomize the order of testing because it allowed subjects to experience the feeling of the test and decreased their apprehension, which was important in a postsurgical cohort.

There was no association between the measures of strength and power and the amount of lengthening. In this series of patients, the range in percentage lengthening was between 5% and 18% with an average of 10.3%. Lindsey et al²¹ have shown in animals that with limb lengthening of between 20% and 30% muscle adaptation occurs by increasing muscle fiber length through serial sarcomere addition. Khakharia et al²² reviewed a series of 16 patients who had undergone similar amounts of lengthening to those reported in this article (mean=4.4cm, mean percentage lengthening of 11.6%) and reported only 2 cases with muscle weakness. However, they assessed muscle strength by using manual testing and the 5-point Oxford scale, which would not be sufficiently sensitive to detect moderate deficits in strength.

We chose to test only concentric muscle strength. Although it would have been interesting to have also tested eccentric strength, this was not performed in order to keep the testing within a reasonable burden for the patients. The collection of concentric isokinetic strength, LEP, and 3 functional activities already required a significant commitment from the patients, and we believed that the additional testing of eccentric strength would have been too onerous for patients who were being tested immediately before surgery or in a relatively early phase of recovery.

The patients in the study were mostly young, with a mean age of 27 years (range, 13–56). Three of the patients were under 18 years old and skeletally immature. Shiska et al²³

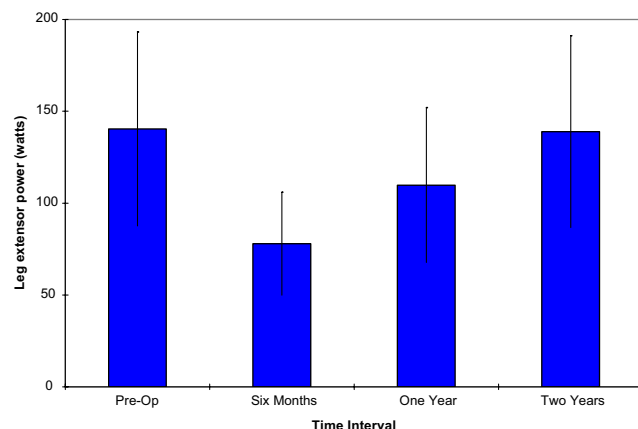


Fig 3. Changes over time in LEP.

Table 3: Correlations Between Muscle Strength and Power and Physical Function Tests

	Pre-op Extensor Strength (Nm)	Pre-op LEP (W/kg)	Pre-op Stairs (No. in 60s)	Pre-op Sit-to-stand (No. in 60s)	Pre-op Walking Speed (m/s)
Pre-op LEP (W/kg)	.858*		.779*	.774*	.301
Pre-op extensor strength (Nm)		.858*	.737*	.770*	.137

*Correlation significant at .01 level.

hypothesised that muscle responses vary with age. In animals, they found that young animals showed a significantly greater proliferative response to distraction than mature ones. They concluded that younger muscle adapts better to lengthening and suggest that it is beneficial to perform leg-lengthening procedures when the patient is younger to achieve optimal functional results. The numbers in our study were too small to assess any difference in response associated with age.

Study Limitations

The major limitation in our study is the heterogeneity of the patients. Patients were of different ages and had varying amounts and percentages of limb lengthening. Most received only femoral lengthening, but some also received correction of the tibia. The underlying reasons for the limb-length discrepancy was also heterogeneous with nonunion and malunion dominating but also cases for congenital deformity and acquired growth arrest. Such variability is common in series of limb-lengthening patients, reflecting the pattern of practice of the average surgeon. We do not believe these limitations jeopardize our conclusions.

CONCLUSIONS

In terms of time to recover, our results would endorse the view that clinically significant improvements in strength, power, and function are unlikely to be detected after 2 years and that any residual deficit in muscle strength that is detected is likely to be permanent. The fact that the operated limbs remained weaker than the unoperated side suggests that despite good recovery from surgery, limitations are likely to persist in performing high-demand functional activities and sport.

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